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# OZONE DEPLETION

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# INTRODUCTION

Within the last decade, concern has risen sharply over the condition of our atmosphere. This has been fueled by a number of disturbing atmospheric observations that include global warming, acid rain and the discovery of a "hole" in the earth's protective ozone layer over the Antarctic.

Heightened concern has led to a tremendous amount of scientific investigation and political rhetoric surrounding these atmospheric problems. Politicians, responding to the demands of the electorate for greater environmental responsibility, are beginning to tackle these global atmospheric crises to a degree unheard of five years ago. This certainly is true in the case of ozone depletion.

Ozone, located primarily in an altitude range between 20 and 40 km, is important to human survival because it prevents up to 90% of the sun's harmful UV-B radiation from reaching the earth's surface. Destruction of the ozone layer would allow increased levels of UV-B radiation to pass through the atmosphere causing increased incidences of skin cancer and cataracts, suppression of the human immune system, damage to crops and aquatic organisms, and enhancement of photochemical smog.

The problem of ozone depletion is global in magnitude, but both the causes and impact are clearly local in nature. Ontario, as the country's largest producer/consumer of ozone depleting chemicals, has a role to play in the search for solutions. Although the participation of industry will be crucial, leadership in this search must come from governments. It is, therefore, important that politicians have up-to-date information on the subject.

This paper attempts to answer many of the general questions that Members may have about the ozone layer: what it is, what it does, what may be causing its destruction and what the resulting environmental and economic impact may be. The main suspects in the destruction of the ozone layer, the chlorofluorocarbons (CFCs), are then examined in detail, focussing upon their uses, levels of production and the problems involved in finding substitutes. Finally, this paper will review the response of government and industry to recent scientific discoveries and predictions concerning the future impact of continued CFC emissions.

## BACKGROUND

Concern for the integrity of the earth's protective ozone layer has arisen on several occasions since the early 1970s. Scientists first postulated that human activity could threaten the ozone layer in 1970 when a West German advanced the theory that emissions of nitrogen from high flying supersonic jets would consume stratospheric ozone in a self perpetuating cycle.[1]

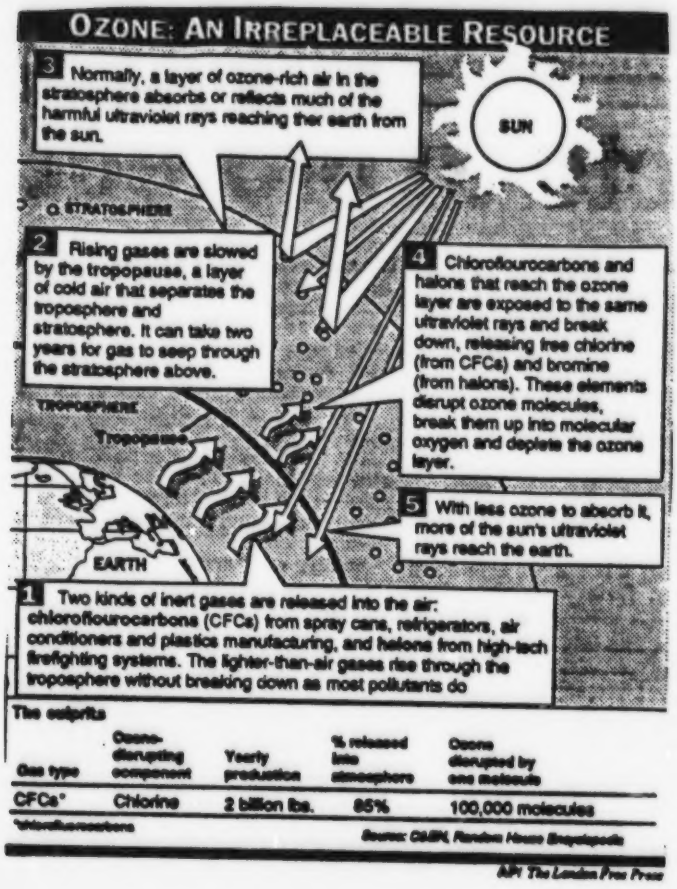
According to this theory, nitric oxide in the jets' emissions could react with the ozone, transform it into simple oxygen and then convert itself back into nitric oxide to repeat the process on another ozone molecule. At the time, calculations based on 500 supersonic transports (SSTs) flying 7 hrs/day over 10 years predicted a 2.2% depletion of the earth's ozone layer. This environmental problem, combined with the high cost of the aircraft, convinced Congress to terminate subsidies for the development of an American SST in 1971.[2]

The second chapter in the ozone story began in 1974 when two researchers in the U.S., Rowlands and Molina, laid the foundation for a theory of ozone depletion that has been at the core of the controversy ever since.[3]

Most chemicals that are emitted into the atmosphere eventually become trapped in one of many natural "sinks" such as the ocean, vegetation or through chemical decomposition into other less harmful molecules. Because CFCs are so chemically inert and relatively insoluble, Rowlands and Molina hypothesized that CFCs emitted into the lower atmosphere (the troposphere) are able to bypass these natural sinks. As a result, these CFCs can drift through the atmosphere for over 100 years, eventually making their way into the upper atmosphere (the stratosphere) where ozone is most abundant and most important (see Figure 1).

At high altitudes, CFCs are exposed to short-waved ultraviolet light whose action chemically decomposes the CFC, releasing chlorine (Cl) atoms. These Cl atoms destroy ozone in a catalytic reaction that is similar to that of nitric oxide (described earlier) but is six times more efficient (see Figure 2). The cycle of ozone destruction would stop only when the chlorine diffused down into the troposphere.[4]

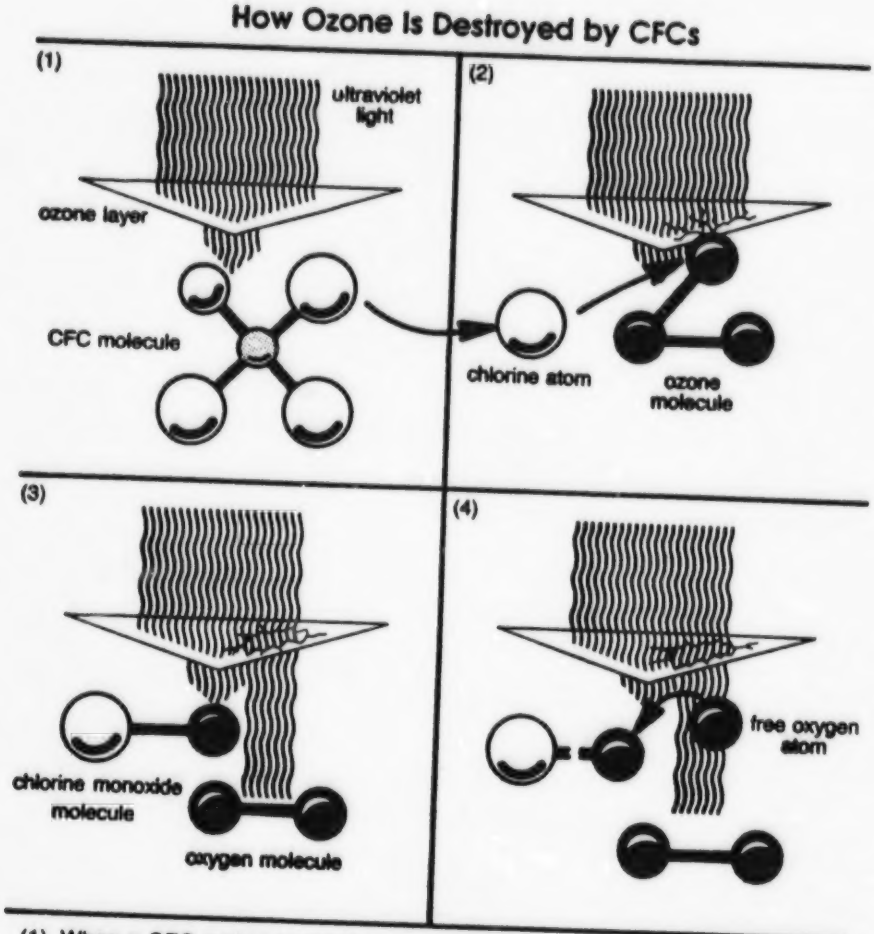
**FIGURE 1**


OZONE: AN IRREPLACEABLE RESOURCE
3 Normally, a layer of ozone-rich air in the stratosphere absorbs or reflects much of the harmful ultraviolet rays reaching ther earth from the sun.
SUN
O STRATOSPHERE
2 Rising gases are slowed by the tropopause, a layer of cold air that separates the troposphere and stratosphere. It can take two years for gas to seep through the stratosphere above.
4 Chlorofluorocarbons and halons that reach the ozone layer are exposed to the same ultraviolet rays and break down, releasing free chlorine (from CFCs) and bromine (from halons). These elements disrupt ozone molecules, break them up into molecular oxygen and deplete the ozone layer.
TROPOSPHERE
Tropopause
5 With less ozone to absorb it, more of the sun's ultraviolet rays reach the earth.
EARTH
1 Two kinds of inert gases are released into the air: chlorofluorocarbons (CFCs) from spray cans, refrigerators, air conditioners and plastics manufacturing, and halons from high-tech firefighting systems. The lighter-than-air gases rise through the troposphere without breaking down as most pollutants do
The culprits
Gas type
Ozone-disrupting component
Yearly production
% released into atmosphere
Ozone disrupted by one molecule
CFCs*
Chlorine
2 billion lbs.
85%
100,000 molecules
*chlorofluorocarbons
Source: CIAP, Random House Encyclopedia
AP/ The London Free Press

Source: London Free Press, 17 February 1989.

Upon hearing news of Rowlands and Molina's findings, environmental groups began applying pressure on Congress to ban CFC aerosol sprays, the largest source of CFC emissions at that time. The official response from governments was slow, and by the time the U.S. finally banned all but essential uses of CFC-based aerosol propellants in 1978, voluntary consumer response had already cut domestic use in the U.S. in half.[5]

## FIGURE 2




(1) When a CFC molecule reaches the ozone layer, it is broken apart by ultraviolet light.
(2) The liberated chlorine atom attacks an ozone molecule, breaking it apart.
(3) A chlorine monoxide molecule and an ordinary oxygen molecule are formed, allowing more ultraviolet light to penetrate through the ozone layer.
(4) A free oxygen atom breaks apart the chlorine monoxide molecule allowing the chlorine to begin the ozone depletion process again. (2)

Source: Cogan, Stones in a Glass House, p. 29.

Canada, Sweden and Norway soon followed the American lead and banned CFC-based propellants in at least 90% of their aerosol products. The European Economic Community adopted a different approach. In 1980, the members of the EEC agreed not to increase their production capacity (producers were operating below capacity so this would still leave room for increased production) and called for a 30% reduction in aerosol propellants by 1982 (based on 1976 consumption figures).[6]

In the six or seven years following the ban of CFCs in aerosols, concern over the ozone layer appeared to subside. In the eyes of the public, the aerosol ban had averted a crisis and solved the problem. Meanwhile, the scientific community was becoming more divided as to the real significance of CFCs in destroying the ozone layer.[7]

It appeared that, in addition to ozone, other natural and manufactured chemicals in the upper atmosphere could react with chlorine. These reactions would transform the Cl into a molecular form that would not destroy ozone. Accordingly, Rowlands and Molina announced that previous estimates of global ozone loss may have been overstated.[8]

By 1980, ozone depletion had become a forgotten issue, taking a back seat to other environmental problems deemed to be more pressing. Meanwhile, increases in the production of CFCs for non-aerosol uses were quickly making up for the losses resulting from the aerosol ban.

Then in 1985, the entire ozone controversy once again moved to centre stage following the publication of an article by a little-known atmospheric scientist named Joseph Farman, head of the British Antarctic Survey.

Using a simple ground-based device employing a technique dating back to the 1920s, Farman reported that his group had detected large and unexpected losses of ozone in the stratosphere above the British Research station at Halley Bay.

Skeptically, NASA retrieved and reviewed data collected by orbiting satellites only to find that there was in fact a significant depletion of ozone in the atmosphere over much of the Antarctic Continent. This "hole" in the ozone extended over an area as large as the continental U.S. and was as thick as Mt. Everest is tall.[9]

# OZONE

## What is Ozone?

The chemical ozone is a molecule made up of three atoms of oxygen, hence its chemical symbol $O_3$. This can be compared to common oxygen which contains two atoms of oxygen ($O_2$). Ozone concentrations in the atmosphere are controlled by a number of reactions that combine and remove oxygen atoms. The level of ozone in the atmosphere is the result of a balance between rates of production and rates of destruction. Therefore, anything that affects the rates of these reactions can result in a new, either higher or lower, equilibrium level of ozone.

Catalysts are chemicals that increase the rate of a chemical reaction without being consumed or permanently changed in the process. As a result, a single catalytic molecule can be involved in many repeated reactions. Examples of catalysts that participate in the breakdown of ozone include atomic chlorine (Cl), atomic bromine (Br), nitrogen oxides ($NO_x$) and hydrogen oxides ($HO_x$) (see Figure 2). It is estimated that a single Cl atom is capable of destroying 100,000 ozone molecules.[10]

## Where is Ozone Found?

Ozone is found throughout much of the atmosphere but it is most abundant in the lower stratosphere in an altitude range of 20 to 40 km.[11] This band of stratospheric ozone is created in part by the intense ultraviolet (UV) light present at that level. UV light is crucial to ozone formation.

In absolute terms, the overall concentration of the ozone in the atmosphere is actually quite low. If all the ozone in the atmosphere were compressed to ground-level pressure, it would form a band only three millimetres thick.[12]

In recent years, a second layer of ozone abundance has been observed at ground level. This recent development is linked to the production of nitrogen oxides and hydrocarbons from automobile exhaust and industrial plants. UV radiation acts to convert these pollutants into ozone. Ironically, ground-level ozone is considered to be a serious pollutant and a major constituent of photochemical urban smog. Studies

have shown that exposure to ozone can cause breathing difficulties, chest pains and nausea in humans. It has also caused damage to crops amounting to between $10 and $30 million per year in Ontario alone.[13]

**What Impact will Ozone Depletion Have?**

The primary beneficial characteristic of ozone in the stratosphere is its ability to absorb UV radiation from the sun. It is estimated that up to 90% of the sun's most damaging rays, UV-B, are screened by ozone in the stratosphere. A 1% decrease in the concentration of stratospheric ozone is expected to increase the intensity of UV-B at the earth's surface by about 2%.

Studies indicate that increased exposure to UV-B can be harmful to humans, animals and plants. According to the U.S. Environmental Protection Administration (EPA), the following impact can be expected:

| | |
|---|---|
| Skin Cancer | Each 1% drop in ozone is projected to result in 4-6% more cases of squamous and basal cell carcinoma -- the two most common but rarely fatal forms of skin cancer. Although the connection between the more deadly malignant melanoma and UV-B is less clear, a 1% drop in ozone could cause as much as a 3% increase in mortality. Most at risk are those with light skin colouring who live nearest the equator.[14] |
| Cataracts | The EPA estimates that a 1.2-6.2% depletion of the ozone layer will result in from 555,000 to 2.8 million cataract cases among Americans born before 2075. Victims will also be stricken earlier in life, making treatment more difficult.[15] |
| Human Immune System | Medical researchers believe that exposure to UV-B suppresses the human immune system, lowering the body's resistance to attacking micro-organisms. This makes the body less able to fight the development of tumours, and renders it more prone to infection by diseases or parasites. Although the extent of immunosuppression cannot yet be quantified, some evidence suggests it could be induced by doses of UV radiation much lower than that required to cause cancer.[16] |

**Vegetation**

Most plants have not been tested for response to UV-B exposure, but of the roughly 200 that have, 70% were found to show some sensitivity. Increased exposure to radiation may decrease photosynthesis, water-use efficiency, yield, and leaf area. The list of sensitive plants includes many of the important agricultural crops such as wheat, rice, corn and soybeans. Studies on soybeans indicate that yields could decline as much as 25% with a comparable increase in UV-B.[17]

**Aquatic Organisms**

Aquatic organisms living in the top layers of the ocean could also be susceptible to increased UV-B. Of particular importance are the microscopic phytoplankton that form the base of the aquatic food chain. If the phytoplankton are affected, then too will be krill, the tiny animals that feed on them, and then fish, seabirds, seals and whales. It has been shown that high doses of UV radiation can kill phytoplankton and that lower amounts can slow photosynthesis. The critical question now is how much UV radiation is penetrating the water column and how this will affect production. Scientists in the Antarctic are currently measuring these effects.[18]

**Tropospheric Pollution**

Some studies have indicated that increasing UV-B could exacerbate smog in urban areas. Depending upon the chemical mix of pollutants in the air, UV rays can trigger the formation of chemical species that generate photochemical smog. As mentioned above, one component of urban smog is ozone. In high concentrations it can damage vegetation, property and human health. It is also a very potent greenhouse gas when found in the troposphere, contributing substantially to overall atmospheric warming.

## CHLOROFLUOROCARBONS

### What are CFCs?

Chlorofluorocarbons (CFCs) are a group of related chemicals made up of various chlorine, fluorine and carbon atom combinations. These chemicals share a number of desirable properties that make them particularly valuable to industry. These include:

- low toxicity;
- non-flammability;
- the ability to produce a fine spray;

- little odour;
- stability during extended storage;
- easily compressed; and
- inexpensive to produce.

Many different CFCs have been developed and are currently in production. To differentiate between them a three-digit code has been developed based on the number of atoms in the molecule. The far right digit is the number of fluorine atoms, the next represents the number of hydrogen atoms plus one and the third digit from the right equals the number of carbon atoms minus one. Therefore, the refrigerant CFC-12 is composed of two fluorine atoms, zero hydrogen atoms and one carbon atom (the zero representing the carbon digit (1-1=0) is usually not written).

**What are CFCs Used For?**

Products that currently depend on CFCs are ubiquitous (see Table 1). CFCs are used as blowing agents in foams used to make seat cushions, packaging and insulation, aerosol propellants for personal care products, and as a solvent in the electronics industry.[19] According to an industry-sponsored group, the Alliance for Responsible CFC Policy, the market value of CFCs produced in the U.S. in 1987 was roughly $750 million annually. The value of goods and services directly dependent on the chemicals was $28 billion and the end-use value of installed equipment and products was $135 billion (all US$).[20]

Halons are closely related to CFCs. The only difference is the replacement of chlorine atoms with bromine atoms. Halons appear to act in ways similar to CFCs, as far as chemical characteristics are concerned, but they have up to ten times the ozone depleting potential of CFCs per molecule.

Halons are even less flammable than CFCs. For this reason they have become the world's most advanced weapon against fire, especially in enclosed areas where delicate equipment or artifacts are being stored. Because the gas is inert and leaves no residue, it can be used to flood a room completely, smothering the fire without affecting the room's contents.

**Current CFC Emissions**

Today, five "fully halogenated" chlorofluorocarbons are on the market: CFC-11, CFC-12, CFC-113, CFC-114 and CFC-115 (fully halogenated means that these compounds lack hydrogen, an element that tends to break apart CFCs after they have been released into the atmosphere). In the U.S., the first three accounted for 97.5% of total CFC production in 1987 (see Table 1).[21]

Two other chlorine-containing compounds, carbon tetrachloride and methyl chloroform, have also been identified as strong ozone-destroying chemicals. Carbon tetrachloride is used in Canada and the U.S. to produce CFCs, but in the Soviet Union, Eastern Europe and in many developing nations it is also used as a solvent and as a component of pesticides, synthetic rubber and dyes. Methyl chloroform is another related substance that is widely used as a computer solvent and degreaser.[22]

In 1987, global CFC production (excluding China, the Soviet Union and Eastern Europe) topped 900,000 tonnes, surpassing the production peak set in 1974 prior to the American and Canadian aerosol ban. Only about two dozen firms make CFCs, but production data are scarce and not totally reliable since this information is considered proprietary by the producers. This makes it difficult to analyze and regulate CFC markets.[23]

TABLE 1

## Primary Uses of CFCs and Halons

| Application | Primary Compound(s) Used and Amount Used in U.S. in 1985 (millions of pounds) | | Where or How Used |
|---|---|---|---|
| Stationary air conditioning and refrigeration | CFC-12<br>CFC-11<br>CFC-115<br>CFC-114 | 68.5<br>14.5<br>9.9<br>2.2 | ◆ 45 million homes and most commercial buildings<br>◆ 100 million refrigerators<br>◆ 30 million freezers<br>◆ 180,000 refrigerated trucks<br>◆ 27,000 refrigerated rail cars<br>◆ 250,000 restaurants<br>◆ 40,000 supermarkets<br>◆ 160,000 other food stores |
| Mobile air conditioning | CFC-12 | 120.0 | ◆ 90 million cars and light-duty trucks |
| Plastic foams | CFC-11<br>CFC-12<br>CFC-114 | 150.7<br>48.2<br>6.6 | ◆ rigid insulation for homes, buildings and refrigerators<br>◆ flexible foam cushioning<br>◆ food trays and packaging |
| Solvents | CFC-113 | 150.7 | ◆ microelectronic circuitry, computers and high-performance air and spacecraft<br>◆ dry cleaning |
| Sterilants | CFC-12 | 26.4 | ◆ medical instruments and pharmaceutical supplies |
| Aerosols | CFC-12<br>CFC-11 | 15.6<br>9.9 | ◆ essential uses in solvents, medicines and pesticides |
| Miscellaneous | CFC-12 | 22.0 | ◆ food freezants for shrimp, fish, fruit and vegetables |
| Fire extinguishment | Halon 1301<br>Halon 1211 | 7.7<br>6.2 | ◆ computer rooms, telephone exchanges, storage vaults |

Source: Cogan, Stones in a Glass House, p. 15.

Refrigeration and air conditioning are the largest users of fully halogenated CFCs in the U.S. with an estimated 39% of market share. Foam blowing agents are second at 28%, while solvent use ranks third with a 23% market share. Other uses of CFCs are minor by comparison, although it is interesting to note that aerosols, once the dominant CFC use, are now limited to a 4% market share for government-exempted "essential" uses.[24]

Worldwide, aerosols continue to be a major user of CFCs. In 1985, aerosols ranked second with a 31% share of the market, slightly behind foam blowing agents at 33% and just ahead of refrigerants at 30%.[25]

## OZONE DEPLETION

### Antarctic Ozone Hole

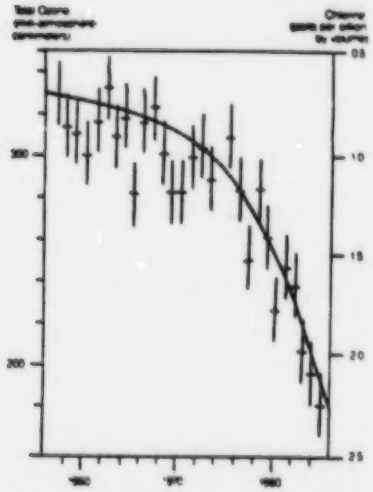
The "hole" in the ozone layer over the Antarctic continent was first reported in the literature in 1985,[26] but it had actually appeared in satellite recordings much earlier. Apparently, computers analyzing the data were instructed to reject values below a certain level as "obviously absurd readings."[27] A careful re-evaluation of satellite records revealed that total atmospheric ozone concentrations over the Antarctic had been decreasing steadily since 1979 (see Figure 3).

The maximum recorded depletion of ozone occurred in the spring (October) of 1987. In that year, total column ozone abundances were reduced by more than 50%. In the "heart" of the ozone hole, at an altitude of between 15 and 20 km, ozone concentrations had decreased by more than 95% of their value two months earlier. The region of ozone disturbance also reached a maximum in 1987, extending as far north as Santiago and Buenos Aires in South America as well as the southern edge of New Zealand and Australia.[28]

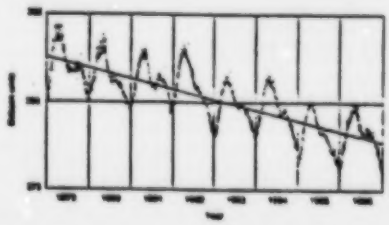
When it first appeared, scientists were unable to explain the cause of the ozone hole. Theories and models involving CFCs and other trace gases did predict greater depletion at the poles, but not to the extent observed in the Antarctic. Plausible theories emerged linking the hole in the ozone to natural changes in springtime wind circulation or to fluctuations in UV radiation associated with the solar cycle. However, most scientists still believed that human-induced increases in atmospheric CFCs were somehow involved in a mechanism that had not yet been discovered.[29]

**FIGURE 3**

## Ozone Decline Above Halley Bay and Globally



Ozone decline above Halley Bay, Antarctica, as measured by a ground-based Dobson spectrophotometer. Measurements began in 1957.



Global ozone decline since 1979 as measured by the TOMS instrument on the Nimbus 7 satellite. Deterioration of the instrument has overstated the global decline, however.

Source: Cogan, Stones in a Glass House, p. 45.

Scientists converged on the Antarctic in the spring of 1986 and 1987 to test the various theories they had postulated. By the beginning of 1988 a consensus began to emerge as to a probable mechanism.

During the winter, a large, swirling mass of cold air forms over the Antarctic continent. This is called the polar vortex. The air within this polar vortex becomes isolated from the air outside it and temperatures can drop to below -80° C. At such low temperatures, moisture in the air can freeze to form ice clouds. These are most abundant in the upper atmosphere and are referred to as polar stratospheric clouds (PSC). These clouds are thought to be the key element of the Antarctic ozone hole.[30]

Previous theoretical models of ozone depletion assumed that all chemical reactions occurred between gases in a gaseous medium. They did not consider chemical reactions that occur on the surfaces of particles such as ice. It is hypothesized that reactions associated with PSCs help to convert inert forms of chlorine into chlorine monoxide (ClO). ClO forms ozone-depleting Cl and molecular oxygen in the presence of UV light. Since the polar vortex creates an isolated mass of air, the concentration of ClO can build up throughout the winter to levels that are up to 50 times greater than those found outside of the vortex.[31]

Sunlight returns to the polar region in the spring. Once the UV rays of the sun strike this isolated mass of air containing high concentrations of ClO, ozone-depleting Cl is formed and a massive reduction of ozone occurs. Depletion will continue until the polar vortex collapses, usually sometime in October when the atmosphere begins to warm. Following the collapse of the vortex, ozone-rich air in the surrounding region will bring ozone levels back to near previous values usually by early to mid-November. However, recovery is not complete and the region south of 60°S latitude has experienced a year-round ozone depletion of about 5% since 1979.[32]

Although many of the details still have to be worked out, most scientists appear to agree that this is the general mechanism operating in the Antarctic atmosphere. At the very least, it appears clear that chlorine (and to a much more limited extent bromine) is directly involved in the depletion of the ozone layer over the Antarctic.[33]

### Ozone Depletion in the Northern Arctic

In January and February of 1989, scientists converged upon the Arctic to see if the mechanism operating in the Antarctic also acts to deplete stratospheric ozone in the Arctic. Temperatures, although not as cold as those in the Antarctic, are cold enough to allow for the formation of a polar vortex and the accumulation of PSCs. The results of experiments conducted by these scientists identified concentrations of chlorine monoxide (ClO) within PSCs that approached the abnormally high levels observed in the Antarctic just prior to ozone depletion. Such high levels of ClO would indicate that chemical reactions are occurring on the surface of ice crystals just as in the Antarctic. Therefore, conditions in the Arctic appear to be ideal for significant depletion of the ozone layer.[34]

Despite these ideal conditions, a substantial thinning of the ozone layer over the Arctic has yet to be observed. In the spring of 1986, a minor thinning of the ozone was observed briefly, but subsequent monitoring in 1987 and 1988 failed to confirm the existence of a northern equivalent to the Antarctic ozone hole. The 1989 expedition appears to have identified the reasons for differences between the two poles.

The winter of 1989 was particularly cold in the arctic upper atmosphere. The polar vortex formed early and remained stable throughout the winter. These conditions allowed for the formation of PSCs in above average amounts, leading to the formation of high concentrations of ClO.

Had the polar vortex persisted through February, the sun, in combination with the ClO, would have destroyed vast quantities of ozone. Depletion rates up to 1.0% per day could have been expected. However, as it turned out, atmospheric warming broke up the polar vortex by mid-February before significant ozone depletion could occur. Although Canadian researchers did report a substantial thinning of the ozone layer in early February, NASA researchers dismissed these observations as being caused by physical conditions (local storms "pushing" a temporary hole in the ozone) rather than by chemical reactions involving CFCs and chlorine.[35]

Under normal atmospheric conditions, the arctic polar vortex is unstable and can even break-up and re-form through the course of the winter. This inhibits the formation of PSCs, limiting overall abundance to roughly one-tenth that found in the Antarctic.[36] Moreover, the vortex break-up and the arrival of early spring sunshine usually occur within a few weeks of each other in February in the Arctic. By comparison, in the Antarctic the vortex can persist for over a month in the spring sunshine.[37]

These two major factors, combined with several other minor factors, create a situation in which an ozone hole as extensive as the one centred on the South Pole is not likely to form in the northern hemisphere except under unusual (but nonetheless possible) climatic conditions.[38]

**Global Ozone Depletion**

The discovery of the Antarctic ozone hole came at a time when research scientists were questioning the significance of ozone depletion and the role that manufactured chemicals played in ozone destruction. When scientists identified chemical sinks in

the atmosphere where chlorine and bromine could be trapped and held in the form of unreactive molecules, the threat to the ozone layer posed by CFCs appeared less ominous. It seemed as if the ban imposed on CFC-based aerosols would be sufficient to protect the ozone. Not surprisingly, the discovery of the ozone hole over the Antarctic caused scientists to rethink many of their assumptions.

Data on stratospheric ozone have been collected from various sources over the years. These sources have not always painted a consistent picture of what is happening to global ozone coverage. For example, satellite data indicated a significant reduction in total column ozone in the order of 1% per year. Meanwhile, ground-based monitoring stations failed to detect the same level of ozone depletion. Clearly, these basic discrepancies needed to be resolved before any meaningful conclusions could be developed.

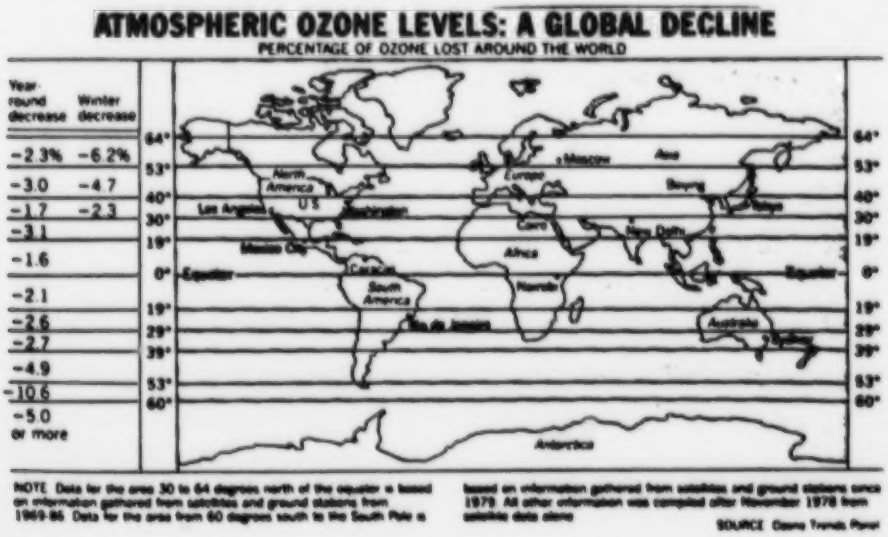
In response to these apparent inconsistencies in data and analysis, NASA assembled a group of over 100 scientists (the Ozone Trends Panel) from around the world to conduct a major re-evaluation of all ground level and satellite ozone data. The results of this re-evaluation were released in March of 1988. Briefly, their findings were as follows:[39]

- The atmospheric concentration of trace gases important in controlling stratospheric ozone levels continues to increase on a global scale because of human activities.
- Total column ozone abundances appear to be affected by three natural, cyclic, geophysical changes: 1) annual cycles of the seasons; 2) stratospheric winds which oscillate with a repeating cycle of about 26 months; and 3) the 11 year solar sunspot cycle. There could also be natural transient effects from other irregular phenomena such as the El Nino currents in the southern hemisphere or sporadic events such as volcanic eruptions.
- After statistically eliminating these effects from the data, the remaining trend indicated a measurable increase in the annual total column ozone of 1.7 to 3.0% in all latitude bands from 30° to 64° in the Northern Hemisphere. The decrease was largest in the winter months, December through March, when ozone levels dropped between 2.3 and 6.2%. These winter values are almost two times higher than the ozone depletion predicted by theoretical models. As noted earlier, year round levels over the Antarctic were found to have decreased by at least 5%, while local springtime depletions have exceeded 50%.
- Satellite data indicating much higher ozone losses (1% per year in the total ozone and 3% per year at an altitude of 50 km.) were found to be affected by equipment deterioration. Using ground-based equipment located in the

northern hemisphere and in the Antarctic, satellite data were adjusted to remove the effect of this deterioration. These data were then combined with ground-based data to provide a complete description of ozone depletion at all latitudes (see Figure 4).

- The next maximum in the solar sunspot cycle is expected in 1991, and theoretical calculations predict that the natural response for ozone to this cycle will be to increase toward a maximum at that time. This natural response may offset or even reverse the predicted decrease in the total column ozone that would result from increases in CFCs and other trace gases. However, after 1991, when solar ultraviolet output begins to decline, total column ozone is again expected to decrease.

FIGURE 4




Source: Cogan, Stones in a Glass House, p. 68.

The Ozone Trends Panel Report was significant in that it cleared up many of the inconsistencies in the data. Moreover, it was the first time a decrease in global ozone levels had been confirmed. Theoretical models did not predict a depletion of this magnitude until sometime in the next century. As a result, the Ozone Trends Panel's analysis transformed next century's problem into today's problem.

## GOVERNMENT RESPONSE

The initial government response to ozone depletion took place in the late 1970s when Canada, the U.S., Norway and Sweden banned CFC propellants in at least 90% of their aerosol products. The European response was an agreement not to increase their industrial production capacity, a hollow gesture at best since actual production was well below industrial capacity at that time. In the mid 1980s the cap was still 30% higher than actual production.[40]

The early 1980s produced little in the way of further CFC controls. This lack of progress was due in part to disagreement within the scientific community over the causes of ozone depletion as well as the non-interventionist approach to industry, dominant in the U.S. and U.K. particularly. Production of non-aerosol CFCs grew so rapidly that by 1986, total global use of CFCs surpassed the previous high point set in 1974 (prior to the aerosol ban).[41]

The discovery of the Antarctic ozone hole in 1985 served to remind policy makers of the seriousness of ozone depletion. As a result, relatively quick agreement was achieved in the signing of the Vienna Convention for the Protection of the Ozone Layer which has served as a vehicle for cooperative research. However, efforts to reach an agreement (a "protocol" to the Convention) on emission curbs became stalemated in late 1985 when major producing countries failed to agree upon the form emission reductions should take. The U.S wanted a worldwide aerosol ban similar to the one already implemented domestically. The Europeans favoured a production cap like the one already in place in Europe.

After two years of negotiation, emission curbs were finally agreed upon. The final accord was worked out during meetings in Europe in July of 1987 and in ten days of negotiation in Montreal in September. The Montreal Protocol was signed by 25 countries, including Canada, on 16 September 1987.[42]

The Montreal protocol freezes CFC production at 1986 levels, and will reduce atmospheric releases by 20% in 1993 and by another 30% in 1998. Halon production is subject to a freeze based on 1986 levels starting in 1992. The agreement allows a 10-year growth period for CFC and halon use by developing countries and permits the

producing countries to make extra CFCs and halons, not counted in their quotas, to fill the needs of developing countries. The Soviet Union, which signed the accord in December of 1987, also receives a special growth allowance.[43]

The protocol came into effect on 1 January 1989, and emission levels were controlled as of 1 July 1989. By 3 May 1989, 36 countries had ratified the protocol.[44]

By conventional diplomatic standards, the Montreal Protocol is a significant accomplishment, but the net result of the agreement, even if it is joined and observed by all countries worldwide, will still only be to slow the rate at which CFCs and halons accumulate in the atmosphere. The U.S. EPA has calculated that even with 100% global participation in the protocol, chlorine concentrations in the atmosphere would triple by 2075.[45]

The reason why the Montreal Protocol will not reduce chlorine concentrations lies in the fact that fully halogenated CFCs can drift in the atmosphere for over 100 years before they break down or are removed (see Table 2). Simply to hold the chlorine content of the atmosphere at prevailing levels, the world would have to reduce emissions by 85%. That would allow the amount of CFCs emitted into the atmosphere to equal the rate at which these compounds are washed out.[46] Therefore, a 50% reduction from today's emission levels would still result in a net increase in atmospheric chlorine concentrations.

TABLE 2

## Characteristics of Ozone-Depleting Compounds

| Compound | Ozone Depletion Potential (CFC-11 = 1.0) | Greenhouse Potential (CFC-12 = 1.0) | Atmospheric Lifetime (Years) | Est. Depletion Contribution (Percentage) |
|---|---|---|---|---|
| CFC-11 | 1.0 | 0.40 | 64 | 25.8 |
| CFC-12 | 1.0 | 1.00 | 108 | 44.7 |
| CFC-113 | 0.8 | 0.3 - 0.8 | 88 | 11.7 |
| CFC-114 | 1.0 | 0.5 - 1.5 | 185 | * |
| CFC-115 | 0.6 | 1.0 - 3.0 | 380 | * |
| HCFC-22 ** | 0.05 | 0.07 | 22 | 0.4 |
| Halon 1211 | 3.0 | ? | 25 | 1.0 |
| Halon 1301 | 10.0 | 0.80 | 110 | 3.7 |
| Methyl chloroform ** | 0.1 | 0.01 | 8 | 5.1 |
| Carbon tetrachloride ** | 1.06 | 0.05 | 67 | 7.6 |

* not included
** not regulated under the Montreal Protocol

Source: Cogan, Stones in a Glass House, p. 37.

Moreover, the damage presently observed in the ozone layer is the result of CFCs released into the atmosphere a decade ago. Even if we reduced CFC emissions today to zero, ozone concentrations would likely continue to deteriorate as CFCs from the last ten years slowly make their way up to the stratosphere.

These flaws in the Protocol were known to negotiators prior to signing, but were considered to be an acceptable price to pay in order to achieve a reasonable level of support. However, since the signing of the Protocol in 1987, the Ozone Trends Panel has shown that the current level of ozone depletion is already greater than the amount that treaty negotiators expected in 100 years. In addition, several chemicals not regulated under the treaty have been found to be major threats to the ozone layer; most notably methyl chloroform and carbon tetrachloride. Together, these two chemicals accounted for 13% of total ozone-depleting chemical emissions in 1985 (see Table 2).[47]

Since the signing of the Montreal Protocol, a number of significant political events have occurred in response to these new scientific findings. In 1988, Sweden became the first country to introduce and pass regulations pledging to virtually eliminate the consumption of CFCs and halons by the year 1995. Norway and then Canada followed suit in early 1989. However, the direct impact of these pieces of legislation will be minimal since together these three countries consume less than 5% of the world's CFCs.[48]

In February of 1989, Ontario became the first Canadian province to pass legislation banning the manufacture and use of CFCs and halons. Amendments to the Ontario Environmental Protection Act provided for a staged reduction which began in July of 1989. CFC aerosols and rigid foam packaging were the first to be banned, followed by rigid foam insulation, furniture foam, solvents and finally refrigerants in 1998. In addition, the legislation calls for mandatory recycling of refrigerants and fire extinguisher halons in the interim, and the eventual banning of halon release during fire extinguisher tests.[49]

In March of 1989, the European Community surprised the world by becoming the first major CFC producer to agree to a virtual elimination of CFC production and consumption by the year 2000. This was followed almost immediately by an announcement from Washington that the U.S. was imposing a similar ban.[50]

While politicians in the west appear to be making every effort to act firmly on ozone depleting substances, the developing countries' commitment to protect the ozone layer is tempered by their desire to attain some of the comforts that have been enjoyed by the developed countries for decades. The leaders of these developing countries are worried that CFCs are being banned just as many are reaching an economic position where their people can afford the refrigerators, air conditioners and foam products that use CFCs. If the industrialized countries want the developing countries to move directly to using the more expensive CFC substitutes, they must be willing to subsidize the transfer of materials and technology to these developing countries.[51]

Presently, the developing countries' share of world consumption is only about 16% and their per capita consumption is less than one-sixth that of the U.S. But the potential for growth in CFC consumption in the developing countries is very large. If the developing nations do not participate in the ban, and continue to increase consumption according to their current economic plans, chlorine concentrations in the atmosphere could continue to grow at an alarming rate.[52]

In an effort to address and rectify some of these problems surrounding the Montreal Protocol, 80 nations gathered in Helsinki, Finland in early May 1989 to review recent events and to discuss possible changes. By consensus, a declaration was adopted agreeing "to phase out the production and the consumption of CFCs controlled by the Montreal Protocol as soon as possible, but not later than 2000."[53] The consensus is essentially a declaration of intent. A meeting of all signatories will be held in the spring or summer of 1990 to discuss actual amendments to the protocol.

At Helsinki, the industrialized nations also agreed to help developing nations adhere to a worldwide ban on CFCs. Although they fell short of establishing a special international fund to help developing countries acquire new technologies themselves, they did not exclude the possibility and ordered a report for future consideration. Despite efforts by the U.S., the agreement still does not cover carbon tetrachloride or methyl chloroform and does not require a phase-out of halon gases.[54]

## INDUSTRY RESPONSE

CFCs are part of a multi-billion dollar business worldwide. In the U.S. alone, the end-use value of installed equipment and products using CFCs has been estimated at $135 billion (U.S.). Canada produces approximately $45 million (Can.) worth of

CFCs annually, representing less than 3% of the world's total CFC production. Canadian CFCs are produced by two companies: Du Pont Canada (approx. 65% of total production) and Allied Chemicals (35% of total production).[55]

Initially, producers such as Du Pont and Allied Chemicals lobbied against the imposition of CFC restrictions. In 1975, Du Pont took out a full page advertisement in the New York Times announcing that "should reputable evidence show that some fluorocarbons cause a health hazard through depletion of the ozone layer, we are prepared to stop production of the offending compound."[56] However, for almost 13 years the company maintained that "scientific evidence does not point to the need for dramatic CFC emission reductions."[57] This was before the release of the Ozone Trends Panel Report.

On 24 March 1988, nine days after the Panel Report was released, Du Pont admitted that CFCs were likely contributing to ozone depletion and announced a 95% reduction in the company's production of fully halogenated CFCs by shortly after the beginning of the next century. This announcement was followed immediately by a similar commitment from America's third largest CFC producer, Pennwalt Corp. Clearly, the industry had seen the writing on the wall. Almost overnight, priorities within the industry shifted from protecting CFCs to phasing them out and developing alternatives.

Du Pont has admitted that the problem of finding suitable alternatives to presently used CFCs is not difficult technically.[58] The problem is in finding substitutes that are safe, non-toxic, sufficiently inexpensive to produce and can replace existing chemicals with a minimum of equipment modifications. Du Pont has already spent almost $100 million (U.S.) to develop CFC alternatives and expects to spend more than $1 billion to restructure completely its CFC business throughout North America. Although the cost and the risks are great, the potential for future gains is substantial.[59]

Most alternatives are created by either substituting or removing chlorine from the molecule, or by adding extra hydrogen. The addition of hydrogen (creating hydrochlorofluorocarbons [HCFCs] or soft CFCs) makes the chemical less stable so that it is more likely to break down in the lower atmosphere (the troposphere) before it can make its way up to the stratosphere. Unfortunately, these changes result in complications that make the production process less efficient and the production yields less pure. Production costs for many proposed substitutes appear to range from two to five times higher than the cost of producing CFC-11 or CFC-12.[60]

Another major problem is the length of time required to complete toxicity tests on new commercial products. Applications for the production and sale of a new product can often take 15 to 20 years. By cooperating during toxicity tests through sharing test results and other non-proprietary information, CFC producing companies hope to reduce the time to 5 to 7 years. Yet even with such cooperation, company officials feel that the scheduled phase-out does not leave enough time to bring safe and adequate replacement products to market unless the government agrees to loosen its approval requirements.[61]

A further consideration in the search for appropriate substitutes is the greenhouse effect. In addition to being ozone depleters, CFCs and other related compounds are strong greenhouse gases. CFC-12 is estimated to be roughly 10,000 times more effective per molecule at warming the atmosphere than carbon dioxide.[62] The greenhouse potential of currently used CFCs and proposed CFC substitutes can be found in Tables 2 and 3. However according to Dr. Robert Watson of NASA, these figures are "very preliminary and . . . the greenhouse potentials of the replacements are difficult to estimate."[63]

All of this is very important to industry because it does not want to spend billions of dollars adapting to the production and use of new "ozone friendly" chemicals only to have these replacements banned in the future because of their toxicity or their contribution to global warming.[64]

## CFC SUBSTITUTES

The search for CFC substitutes began in the middle to late 1970s following initial reports of potential ozone depletion. Research efforts waned during the early 1980s, but not before several promising substitute compounds had been identified. This early research provided the foundation for the current development of substitutes that has taken place over the last three years (see Table 3). When Du Pont announced it would phase all CFCs out of production by the turn of the century, the company was already the acknowledged leader in the race for substitutes. In fact, it had two chemical substitutes already in production.[65]

TABLE 3

## Chlorofluorocarbon Alternatives

| Number | Potential Application | Manufacturing Process | Toxicity | Ozone Value[1] | Greenhouse Value[2] |
|---|---|---|---|---|---|
| FC-21 | Blowing agent | Yes | Toxic[3] | <0.05 | <0.10 |
| -22 | Refrigerant, blowing agent | Yes[4] | Low | 0.05 | 0.07 |
| -31 | Propellant | No[5] | Toxic[3] | <0.05 | <0.10 |
| -123 | Blowing agent, refrigerant | CD[6] | Low | <0.05 | <0.10 |
| -124 | Refrigerant, blowing agent | CD[6] | Unknown | <0.05 | <0.10 |
| -125 | Refrigerant | CD[6] | Unknown | 0 | <0.20 |
| -132b | Cleaning agent | No | Teratogen[3] | <0.05 | <0.10 |
| -133a | Blowing agent, propellant | No[5] | Embryotoxin[3] | <0.05 | <0.10 |
| -134a | Refrigerant | CD[6] | Incomplete | 0 | <0.10 |
| -141b | Propellant, blowing agent | Yes[7] | Incomplete | <0.05 | <0.10 |
| -142b | Propellant | Yes[4] | Low | <0.05 | <0.20 |
| -143a | Refrigerant | No[5] | Incomplete | 0 | <0.30 |
| -152a | Propellant, refrigerant | Yes[4] | Low | 0 | <0.10 |

[1] Ozone depletion rating compared with CFC-11, with a value of 1.0. Where '<' sign appears, estimates are based on preliminary or incomplete data.
[2] Greenhouse potential compared with CFC-12, with a value of 1.0. Where '<' sign appears, estimates are based on preliminary or incomplete data.
[3] Work discontinued principally for this reason.
[4] Commercially available compound.
[5] Manufacturing process available but has not been commercialized.
[6] Catalyst deficiency for manufacturing process.
[7] Developmental process only.

Source: Cogan, Stones in a Glass House, p. 78.

**Aerosol Propellants**

Aerosols are still the largest source of CFC emissions worldwide, contributing almost one-third to the combined global emission of CFC-11 and CFC-12. This is one of the easiest sources to control since HCFC substitutes are already commercially available.

As mentioned earlier, Canada, the U.S., Sweden and Norway banned CFCs from aerosols in the late 1970s. Since then, Denmark banned aerosol propellants in 1987, and voluntary industry cutbacks of 90% by the end of 1989 were announced by Belgium, the Netherlands, Switzerland, the U.K. and West Germany. The Soviet Union declared its intention to switch to non-CFC propellants by 1993, leaving only France, Japan, Eastern Europe and the developing countries without control measures.[66]

**Refrigerants**

The refrigeration and air conditioning industry consumes almost half of the CFC-12 produced each year worldwide. This high consumption figure is largely due to leakage during recharge/repair service, losses during manufacturing and further leakage through accidents and after disposal. Therefore, better maintenance practices using more highly trained service technicians could reduce CFC consumption substantially. Also, recovery from discarded refrigerators could be instituted either by governments or through the offering of some kind of a bounty to encourage scavenging.[67]

The automobile air conditioning market is the largest single user of CFC-12 in the U.S., and lost coolant from automobile air conditioners accounts for an estimated 16% of total ozone depletion. Forty-eight percent of released CFC escapes during servicing when coolant is simply vented into the air. It will soon be possible to pump coolant out of the compressor, purify it and re-inject it into the automobile using a machine known as a "vampire."[68]

Although a number of possible substitutes are currently being tested, the most likely replacement for CFC-12 in refrigeration units is HFC-134a, a fluorocarbon that does not contain chlorine so it does not damage the ozone layer. From the industry's perspective, HFC-134a is promising since its utilization would require only minor modifications to compressor designs.

However, HFC-134a must still pass chronic toxicity tests and a compatible lubricant must be developed that will work with the refrigerant. As a result, HFC-134a is not expected to be on the market for another five to seven years. The substitute will likely sell for about $2 (U.S.) per kilogram, or roughly seven times the current price of CFC-12.

In home air conditioners, HCFC-22 has already captured much of the market. This chemical has only 5% of the ozone-depleting capacity of CFC-11 and only 7% of the global warming potential of CFC-12. It has a low toxicity rating and can be manufactured almost as inexpensively as CFC-12. It is only used for air conditioning units because it is not efficient enough to attain the low temperatures required for most refrigeration units.[69]

**Blowing Agents**

The manufacture of flexible foams for furniture cushions and carpet padding results in the immediate release of CFCs. New ventilation systems and process changes are now capable of recovering 85% of these blowing agents for reuse.

Long term replacements for CFC blowing agents in flexible foams and foam packaging appear to be fairly numerous. Carbon dioxide and methylene chloride are both currently used to manufacture foam cushions but the product is markedly less puffy. Meanwhile, the widespread use of hydrocarbon blowing agents and HCFC-22 has enabled fast food packagers to eliminate CFCs from their products since the end of 1988. The elimination of CFCs from other packages is expected to follow shortly.[70]

Manufacturers of rigid foam insulation are finding it much more difficult to find an adequate replacement for CFCs since blowing agents, on average, represent 20% or more of the cost of manufacturing the final product. This percentage is higher than for any other CFC related industry. Therefore, the industry is extremely vulnerable to the higher costs associated with most CFC substitutes. It is expected that a significant contraction of the foam blowing industry is expected whenever proposed regulations go into effect.[71]

Rigid foam insulation manufacturers must also be concerned with the heat-conducting properties of CFC substitutes. Much of the foam's insulating capacity comes from the

CFC gas trapped inside the closed cells of the foam. CFC substitutes that are better thermal conductors will reduce the product's insulating capacity and would, therefore, not be suitable.

Another related industry affected by foam insulation is refrigeration. In addition to its use as a refrigerant, CFC blown foam is used to insulate the refrigerator box. In fact, the refrigerant only accounts for 20% of the CFC contained inside today's refrigerator. The remaining 80% is found in the insulation. As a result, the industry is caught between two competing demands. The need for greater energy efficiency calls for more insulation, but protection of the ozone makes the use of that insulation undesirable. The industry is currently experimenting with vacuum insulation, similar to the kind used in thermos bottles.[72]

**Cleaning Solvents**

Since 1978, CFC-113 has become the fastest growing member of the chlorofluorocarbon family. This growth is directly related to the phenomenal expansion of the computer industry which uses CFC-113 as a solvent because of its superior cleaning abilities.

It appears that CFC-113 should be relatively easy to control since its use is restricted to one industry and the chemical is not incorporated into the final product. Because of its relatively high price, many companies already recycle a considerable proportion of what they use. At AT&T in Denver, recycling equipment costing $41,000 to install yielded savings of $250,000 in 1985 alone by reducing CFC-113 solvent waste by 80%.

Although CFC-113 has become the solvent of choice for the computer industry, it appears that it is not the solvent of necessity. According to a panel of experts convened by the EPA, it is technically feasible to eliminate 98% of the current use of CFCs in "non-surface-mount" applications by substituting a water-based cleaning process.

Petroferm and AT&T have announced the creation of a new water-based solvent that derives its cleaning power from orange rinds. According to AT&T, the new product, "Bioact EC-7," effectively removes soldering residue from surface-mounted chips on printed circuit boards. It is at least as effective as CFCs for about the same price. Analysts estimate that the new product could substitute for 30 to 55% of total projected CFC-113 use in the U.S. electronics industry.[73]

**Halons**

Halons contain bromine, an even more potent ozone destroyer than chlorine. These compounds are used primarily in fire fighting equipment. Although there are no promising substitutes on the horizon, their emissions should be relatively easy to reduce since the testing of fire fighting equipment now contributes more to emissions than does actual fire fighting. By using alternative chemicals and other testing procedures, and by eliminating accidental discharges, annual emissions could be cut by two-thirds.

Another large source of halon emissions is fire fighter training. Recently, the U.S. military has introduced the use of simulators that do not require actual chemical release. The military is also increasing its use of directed Halon 1211 fire fighting systems over total flooding Halon 1301 systems. This will not only reduce the volume of halons required but also diminish their ozone-depleting potential since Halon 1211 has less than one-third of the ozone-depletion potential of Halon 1301.[74]

## SUMMARY AND CONCLUSIONS

Concern for the integrity of the ozone layer has waxed and waned throughout much of the 1970s and the early 1980s. However, with the discovery of a large "hole" in the ozone layer over the Antarctic continent, the problem seemed to take on a new seriousness. Scientific research has been stepped up considerably and the uncertainty surrounding the depletion of the earth's protective ozone has been reduced considerably.

Ozone is important to human survival because it prevents up to 90% of the sun's harmful UV-B radiation from reaching the earth's surface. Destruction of the ozone layer would allow increased levels of UV-B to pass through the atmosphere leading to increased incidences of skin cancer and cataracts, suppression of the human immune system, damage to crops and aquatic organisms, and enhancement of photochemical smog.

Scientific research has all but confirmed the linkage between chlorofluorocarbons (CFCs) and the destruction of the ozone layer. CFCs are ubiquitous in our society, used as a refrigerant in our air conditioners and refrigerators, as a blowing agent for

most foam packaging products, soft foam cushions and rigid foam insulation, and as solvents in the manufacture of computer chips. A related group of substances, the halons, are even more damaging to the ozone layer than CFCs. These are used primarily in fire fighting equipment.

Since 1986, governments have reacted surprisingly quickly in addressing the problem of ozone depletion. In 1987, the Montreal Protocol was signed calling for a 50% reduction in CFC production by 1995. Scientific evidence released after the signing of the Protocol indicated that these reductions were insufficient to protect the ozone layer. As a result, several countries including Canada, the U.S. and the members of the European Community (EC) promised to virtually eliminate the production of CFCs by the end of the century.

CFC producing companies are now scrambling to develop and gain approval for CFC substitutes. Although viable alternatives appear to be available for most CFC uses, production costs tend to be higher, and the substitutes are often less effective than the original CFCs. Also, questions of safety, toxicity and other environmental impacts have yet to be sorted out.

Despite the recent advances made in reducing CFC production and consumption, the problem is a long way from being solved. Many of the developing countries have not yet agreed to the principles of the Montreal Protocol and refuse to participate in CFC reduction efforts unless developed countries agree to make available the technology necessary to produce CFC substitutes in their own countries.

These developing countries are just now reaching a level of economic prosperity where they can afford CFC containing products. They are not prepared to forgo their refrigerators and air conditioners; nor are they willing to pay higher prices for substitutes to increase the profits of companies in developed countries. If the industrialized countries want the developing countries to move directly to using the more expensive CFC substitutes, they must be willing to subsidize the transfer of materials and technology to these developing countries.

Some CFCs stay in the atmosphere for well over 100 years. As a result, the earth is already committed to a certain level of ozone depletion based on what we have already released into our atmosphere. Simply to hold the chlorine content of the atmosphere at prevailing levels, the world would have to reduce emissions by 85%. That would

allow the amount of CFCs emitted into the atmosphere to equal the rate at which these compounds are washed out.[75] Therefore, until emission reductions of 85% are reached, chlorine concentrations will continue to grow.

Any unnecessary delay has a cost attached to it. By the same token, CFCs are part of a multi-billion dollar industry that produces products upon which all of society has grown to depend. Therefore, acting in haste could prove irresponsible.

Part of the delay in implementing controls is due to trying to produce substitutes as inexpensively as possible. Substitute compounds will undoubtedly cost the consumer more to purchase, but this is likely a fair price to pay for the protection of the ozone layer as a screen against harmful UV-B radiation. A more legitimate reason for delay is the testing required to ensure that CFC substitutes are safe for human handling and are not harmful to the environment.

Clearly, society is going to have to adapt to life without CFCs. The question now becomes a matter of cost, inconvenience, and the safety of the substitutes. The apparent "fall from grace" of CFCs from wonder chemical in the 1940s, 50s and 60s to a threat to our survival in the 1980s and 90s points to the fragile nature of our environment, and to the limits of our understanding.

Although it is encouraging to see governments of the world react as quickly as they have to this renewed crisis, there are many who point to the fact that if warnings were heeded 15 years ago when the problem was first identified, the task of protecting and replenishing the ozone layer would have been many times easier and far less expensive. These people hope that the mistakes committed by delaying action regarding ozone depletion will not be repeated for other environmental problems such as the greenhouse effect, acid rain or the proliferation of persistent toxins in our environment.

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